TITLE OF THE INVENTION

IMAGE PICK-UP APPARATUS AND IMAGE PICK-UP SYSTEM, AND METHOD FOR MANUFACTURING IMAGE PICK-UP APPARATUS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an image pick-up apparatus and an image pick-up system, and a method for manufacturing the image pick-up apparatus. The present invention relates, for example, to an image pick-up apparatus provided with a scintillator layer for converting an incident radiation such as X-ray to a light having a wavelength detectable with the photoelectric conversion element on a sensor substrate on which plural pairs of a photoelectric conversion element and switching element are disposed, and an image pick-up system, and a method for manufacturing the image pick-up apparatus.

Description of the Related Art

A system for converting a radiation such as X-ray into a light having a wavelength in a sensing region with a scintillator and for converting the light into an electric signal with an image sensor to store and transfer as an image data is noticed in the fields of medical inspection and nondestructive testing.

An image pick-up apparatus is disclosed in Japanese Patent

2055 Laid-open No. 7-27863 as an example of the image pick-up apparatus such as a radiation image pick-up apparatus for use in the system as described above, wherein CsI is used for the scintillator material for converting X-ray into a light and the CsI elements are disposed on a two-dimensional substrate.

Meanwhile, high sensitivity is required for the image pick-up apparatus for completing the medical inspection and nondestructive testing within a short period of time in order to reduce X-ray dosage to the testing subjects and human body by taking the effect of radiation into considering.

Accordingly, development of an image pick-up apparatus that can efficiently convert a radiation such as X-ray into an electric signal is desired.

SUMMARY OF THE INVENTION

Accordingly, the object of the present invention is to provide an image pick-up apparatus for enabling it to be highly sensitive and a method for manufacturing the same, and an image pick-up system.

An another object of the present invention is to provide an image pick-up apparatus having a wavelength converter with excellent characteristics and a method of for manufacturing the same, and an image pick-up system.

An additional object of the present invention is to provide an image pick-up apparatus having a high reliability and improved

durability and a method for manufacturing the same, and an image pick-up system.

An another object of the present invention is to provide an image pick-up apparatus being able to increase substantial aperture of pixels of the image pick-up apparatus for making sensitivity of the apparatus high and enhancing reading speed and a method for manufacturing the same, and an image pick-up system.

In a first aspect, the present invention provides an image pick-up apparatus comprising a wavelength converter for converting an incident radiation to a light having a wavelength detectable with a photoelectric conversion element on a sensor substrate on which plural photoelectric conversion elements and a switching elements are disposed, wherein a flattening layer having a flat face making a contact with the wavelength converter is provided between the sensor substrate and wavelength converter.

In accordance with another aspect of the present invention, the present invention provides an image pick-up apparatus comprising plural sensor substrates on which plural photoelectric conversion elements and switching elements are disposed, wherein the plural sensor substrates comprise flattening layers and a wavelength converter is provided on each flattening layer.

In accordance with a further aspect of the present

invention, the present invention provides an image pick-up apparatus comprising a wavelength converter for converting an incident radiation into a light having a wavelength detectable with the photoelectric conversion element on a sensor substrate comprising plural photoelectric elements and switching elements, wherein a flattening layer having a flat plane making a contact with the wavelength converted is provided between the sensor substrate and scintillator layer; or image pick-up apparatus comprising plural sensor substrates on which plural photoelectric conversion elements and switching elements are disposed, a flattening layer being provided on the plural sensor substrates and the wavelength converter being provided on the flattening layer; and an image pick-up system comprising a signal processing device for processing the signal from the image pick-up apparatus, a recording device for recording the signal from the image processing device, and a display device for displaying the signal from the image processing device.

In accordance with another aspect of the present invention, the present invention provides a method for manufacturing an image pick-up apparatus comprising the steps of: forming a protective layer on a sensor substrate comprising plural photoelectric conversion elements and switching elements; forming a flattening layer having a flat surface on the protective layer; and forming a wavelength converter on the flattening layer.

In accordance with another aspect of the present invention, the present invention provides a method for manufacturing an image pick-up apparatus comprising the steps of: forming a protective layer on a sensor substrate comprising plural photoelectric conversion elements and switching elements, flattening the surface of the protective layer; and forming a wavelength converter on the flattened protective layer.

In accordance with another aspect of the present invention, the present invention provides a method for manufacturing an image pick-up apparatus comprising the steps of: providing a flattening layer on plural sensor substrates after disposing the plural sensor substrates comprising plural photoelectric conversion elements and switching elements; and providing a wavelength converter on the flattening layer.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates an equivalent circuit diagram of the sensor provided on the sensor substrate.

Fig. 2 denotes a schematic cross section of the sensor.

FIG. 3A denotes a schematic cross section for describing one example of the manufacturing step of the image pick-up apparatus.

FIG. 3B denotes a schematic cross section for describing A ~~an~~ another example of the manufacturing step of the image pick-up apparatus.

FIG. 4A denotes a schematic cross section for describing ~~an~~ another example of the manufacturing step of the image pick-up apparatus.

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FIG. 4C denotes a schematic cross section for describing ~~an~~ another example of the manufacturing step of the image pick-up apparatus.

FIG. 5 denotes a schematic cross section for describing the polishing area.

FIG. 6 denotes a schematic cross section of the image pick-up apparatus.

FIG. 7 illustrates an example for flattening the surface of the scintillator.

FIG. 8A denotes a schematic plane view for describing an example of the periphery of the image pick-up apparatus.

FIG. 8B denotes a schematic cross section for describing an example of the end face of the image pick-up apparatus.

FIG. 9A denotes a schematic cross section for describing an example of the fabrication step of the image pick-up apparatus.

FIG. 9B denotes a schematic cross section for describing an example of the fabrication step of the image pick-up apparatus.

FIG. 9C denotes a schematic cross section for describing an example of the fabrication step of the image pick-up apparatus.

FIG. 9D denotes a schematic cross section for describing an example of the fabrication step of the image pick-up apparatus.

FIG. 10 illustrates an another example of the image pick-up

apparatus.

FIG. 11 illustrates ~~an~~ another example of the image pick-up apparatus.

FIG. 12A denotes a schematic cross section for describing an example of the manufacturing step of the image pick-up apparatus.

FIG. 12B denotes a schematic cross section for describing ~~an~~ another example of the manufacturing step of the image pick-up apparatus.

FIG. 13A denotes a schematic cross section for describing an example of the manufacturing step of the image pick-up apparatus.

FIG. 13B denotes a schematic cross section for describing ~~an~~ another example of the manufacturing step of the image pick-up apparatus.

FIG. 14 denotes a schematic perspective view for describing ~~an~~ another example of the image pick-up apparatus.

FIG. 15 denotes a schematic cross section of the image pick-up apparatus illustrated in FIG. 14.

FIG. 16A denotes a schematic plane view of an example showing the arrangement of the sensor substrates.

FIG. 16B denotes a schematic cross section of a part of the image pick-up apparatus.

FIG. 17A denotes a schematic plane view for describing ~~an~~ another example of the sensor (a pixel).

FIG. 17B denotes a schematic cross section of the sensor.

FIG. 18A denote a schematic plane view for describing an example of disposition of the sensor and peripheral circuits in the image pick-up apparatus.

FIG. 18B denotes a schematic cross section of the image pick-up apparatus.

FIG. 19 shows an illustrative drawing for describing an example of the image pick-up system.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Examples of the sensor substrate shown in FIG. 1 and FIG. 2 applied to the present invention will be described below.

The reference numerals **101** and **102** in FIG. 1 and FIG. 2 denote a PIN type photodiode and a TFT, respectively. The PIN type photodiode **101** and TFT **102** differ in their layer construction and film thickness with each other as is evident from FIG. 2 (detailed constructions will be described hereinafter), causing a large step on the surface of the sensor substrate at the boundary between the TFT and photodiode.

When a non-single crystalline semiconductor, for example an amorphous silicon film (a-Si film) is used for a sensor material and Al is used for a wiring material, a SiN protective film is deposited under restricted deposition temperatures. Accordingly, covering the steps on the surface of the sensor substrate involves some problems to be investigated, although

the surface steps remain even after the steps on the surface has been appropriately covered.

According to the studies by the inventors of the present invention, growth of CsI crystals becomes poor at the steps on bias lines of the PIN type photodiode and peripheral areas, forming distorted crystals to cause decrease of substantial aperture ratio, when a scintillator made of, for example, CsI is formed on the stepped surface. The inventors of the present invention have succeeded in obtaining a scintillator layer having good crystallinity by flattening the surface where the CsI scintillator layer is to be formed.

The difference between the invention described in Japanese Patent Laid-open No. 7-27863 and the present invention will be then described. Japanese Patent Laid-open No. 7-27863 discloses that concave or convex patterns are formed on the substrate to generate cracks at a designated site for forming the scintillator when the scintillator is formed on the substrate. However, it is not disclosed in the patent publication that the steps adversely affect crystallinity of the scintillator layer to decrease its aperture ratio, so that the surface adjoining to the scintillator layer should be flattened in order to alleviate the effect of the step.

The term "radiation" in the present invention refers to a particle beam or an electromagnetic wave, and the term "scintillator" refers to a substance that converts the particle

beam or electromagnetic wave into a light having a wavelength detectable with a photoelectric conversion element. The present invention is advantageously used for X-ray that is used in the medical inspection and non-destructive testing.

Examples according to the present invention will be described hereinafter in detail with reference to the drawings. The examples below describe a X-ray image pick-up apparatus as an example of the image pick-up apparatus.

(Example 1)

The first example of the present invention will be described with reference to a sensor substrate making use of a PIN type photosensor as the photoelectric conversion element and a TFT as a switching element.

FIG. 3A and FIG. 3B denote schematic cross sections for describing examples of the manufacturing steps of the X-ray image pick-up apparatus in Example 1 according to the present invention.

As shown in FIG.3A, a photoelectric conversion element 12 and TFT 13 comprising the PIN type photodiode are formed on a glass substrate 11, on which a SiN protective film 14 is deposited for stabilizing characteristics of the devices.

FIG. 1 illustrates an equivalent circuit diagram and FIG. 2 show a schematic cross section of the sensor substrate. The reference numeral 101 denotes the PIN type photodiode, the

reference numeral 102 denotes the TFT, the reference numeral 103 denotes a signal line, the reference numeral 104 denote a gate line and the reference numeral 105 denote a sensor bias line in FIG. 2.

The reference numeral 201 denotes the glass substrate, the reference numeral 202 denotes the gate line, the reference numeral 203 denotes a gate insulation film, the reference numeral 204 denotes an i-type a-Si active layer, the reference numeral 205 denotes a SiN film, the reference numeral 206 denotes a n^+-type ohmic contact layer, the reference numeral 207 denotes a SD (source-drain) electrode, the reference numeral 208 denotes a lower sensor electrode, the reference numerals 210, 211 and 212 denote p-, i- and n-type Si layers, respectively, the reference numeral 209 denotes a sensor upper electrode, and the reference numeral 213 denotes a SiN protective film in FIG. 2.

The TFT employs an inverse stagger type TFT composed of the SiN gate insulation layer, i-type a-Si active layer and n^+-ohmic contact layer as shown in FIG. 2 in the present invention. The PIN type photodiode is composed of, on the other hand, the p-type a-Si layer, i-type a-Si layer and n-type a-Si layer. In other words, the layer constructions differ between the TFT and PIN type photodiode, consequently forming large surface steps among functional elements on the sensor substrate.

The SiN protective layer 14 is usually formed on the sensor substrate having the construction as described above for

stabilizing the device characteristics.

A polyimide layer as a flattening layer 15 was then coated using a spinner as shown in FIG 3A. Semicofine (LP-62 usually having a viscosity of 600 to 1,000 cps with a solid fraction of 16.5 to 18.5%) made by Torey Co. was used as the polyimide resin. The spin coat conditions were 50 (rpm)/30 (sec) for the first coating and X (rpm)/60 (sec) for the second coating (X = viscosity (cps) × solid fraction (%) × 0.0563).

The flattening layer can be also formed by a screen printing method, roll coater method, spray method, and spray and spin coating method. CsI is deposited thereafter to form a scintillator layer 16 (FIG. 3B). CsI was grown as a columnar crystal in this example since the scintillator may be expected to have higher sensitivity and crosstalk can be reduced. A CsI crystal having good crystallinity could be obtained in this example by flattening the CsI deposition face by forming a flattening layer 15.

(Example 2)

An Al film was coated as a light reflection film (also serves as a protective film) in the second example of the present invention besides flattening the surface of the CsI layer as described in the first example.

FIG. 4A to FIG. 4~~B~~C denote schematic cross sections showing examples of the manufacturing steps of the X-ray image pick-

up apparatus in the second example according to the present invention.

In the lamination step of CsI shown in FIG. 4B, the apparatus is manufactured by the same manufacturing steps explained using FIG. 3A and FIG. 3B.

The surface of the laminated CsI 16 was then flattened. When CsI had been grown as columnar crystals, the surface becomes rough with a roughness of several microns to several tens microns. The surface was flattened using a polyurethane abrasive cloth and silica abrasive in this example in order to uniformly form the reflection film or moisture protective film with good coverage. FIG. 5 denotes a schematic cross section showing the polishing area P. Flattening is also possible using photolithography such as an etch-back method.

An Al film 17 serving as the reflection film and protective film was completed thereafter (FIG. 4C).

(Example 3)

The Al film was formed after forming the polyimide film as a flattening layer on the CsI layer (the scintillator layer 16) in Example 3 of the present invention, instead of polishing the CsI layer as in the second example.

FIG. 6 shows a schematic cross section showing the construction of the X-ray image pick-up apparatus in Example 3 according to the present invention.

The same manufacturing steps as described in Example 1 with reference to FIG. 3A and FIG. 3B are used until the CsI lamination step for manufacturing the X-ray image pick-up apparatus according to the present example.

Then, the polyimide layer as a flattening layer is coated on the laminated CsI layer **16** using a spinner. The surface is flattened by coating a polyimide film with a roughness of several microns to several tens microns when CsI is grown as columnar crystals as described above. The Al film serving as the reflection film and protective film was further formed in order to uniformly form the reflection film or moisture protective film with good coverage. FIG. 7 shows a schematic cross section after forming the polyimide film as a flattening layer and the Al film.

The polyimide film **18** and Al film **17** are also formed on the end faces of the scintillator layer **16** as shown in FIG. 8A and FIG. 8B in this example. The CsI crystals to serve as the scintillator layer **16** are packaged with the polyimide film **15** serving as a first flattening layer and the polyimide film **18** serving as a second flattening layer. In addition, the first and second flattening layers are packaged with the Al film **17** to serve as the moisture protective film. Such construction allows, for example, the CsI crystals constituting the scintillator layer **16** to be protected from ambient atmosphere such as moisture, improving their durability.

FIG. 9A to FIG. 9D illustrate the manufacturing steps when

the polyimide film **18** and Al film **17** are formed on the end face of the scintillator layer **16** on the sensor substrate.

(Example 4)

The same effects can be obtained by covering the sensor substrate including the scintillator layer with a metal foil such as an aluminum foil, instead of the end face treatment as shown in Example 3.

FIG. 10 and FIG. 11 show a schematic cross sections of the X-ray image pick-up apparatus in which the sensor substrate including the scintillator layer is covered after forming the scintillator layer on the flattened sensor substrate. The metal foil **214** is drawn so as to cover the end face of the scintillator layer **211** with inclined faces, and the edge of the foil is bent downward for sealing a part of the sensor substrate with a resin seal **216**. Moisture can be prevented from permeating with an organic or inorganic resin seal **216** in this construction, while protecting the scintillator layer **211** from permeation of moisture by virtue of spaces formed between the metal foil **214** and scintillator layer **211**.

The metal foil **214** is bent along the end face of the scintillator layer **214** in FIG. 11, thereby sealing the circumference of the scintillator layer with the resin seal **216** comprising the organic or inorganic resin. Since the end face of the scintillator layer is covered with a metal in this

construction, permeation of moisture into the scintillator layer can be prevented.

(Example 5)

The CsI deposition surface is flattened by polishing the SiN protective film by CMP (chemical mechanical polishing) in Example 5, instead of using the polyimide film as in Example 3 and Example 4 described above.

FIG. 12A and FIG. 12B show schematic cross sections for describing examples of the manufacturing steps of the X-ray image pick-up apparatus in Example 5 according to the present invention. Since this example is the same as the manufacturing steps in Example 3, except that the SiN protective film is polished for flattening the CsI deposition surface instead of forming the polyimide film, the polishing step is mainly described.

As shown in FIG. 12A, the SiN protective film **14** is flattened by polishing by CMP after forming the SiN protective film **14** so as to fill the surface roughness caused by the PIN type photodiode **12** and TFT **13**. The CsI layer **16**, polyimide film **18** as a flattening layer and Al film **17** to serve as a moisture protective film are formed thereafter by the same method in Example 3 as shown in FIG. 12B. A SiO_2 film may be used as the protective film **14**.

While it is desirable for some portions of the protective film **14** that protect the PIN type photodiode **12** and TFT **13** to

form a minute film so that characteristics of the PIN type photodiode and TFT are not adversely affected, such films are not necessarily formed on the portions merely to be flattened.

(Example 6)

FIG. 13A and FIG. 13B demonstrates schematic drawings when the portions for protecting the PIN type photodiode **12** and TFT **13** are formed of the minute first protective film **14** so as not to adversely affect their characteristics, while the portions for filling the rough portions are formed of the second protective layer **19** comprising the materials that can be readily polished and having a high deposition speed.

A SiN film and SiO_2 film may be formed as the first protective film **14** and a second protective film **19**, respectively, or the first protective film **14** and second protective film **19** may be formed using the same film material (SiN film or SiO_2 film) but changing the deposition method and deposition condition. Examples of the method for forming the first protective film **14** and second protective film **19** using the same material but changing the manufacturing conditions comprise depositing the first protective film **14** by a CVD method using a mixed gas of H_2, N_2 and SiH_4, and depositing the second protective film **19** by a CVD method using a mixed gas of H_2, NH_3 and SiH_4, thereby making it possible to form the protective films without adversely affecting the characteristics of the PIN type photodiode while

improving the deposition speed. Examples of the method for forming the first protective film **14** and second protective film **19** by changing respective manufacturing methods comprise depositing the first protective film by a CVD method using a mixed gas of H_2, N_2 and SiH_4, and depositing the second protective film by a sputtering method.

Of course, it is preferable to protect the scintillator layer in Examples 5 and 6 as in Examples 3 and 4.

While the X-ray image pick-up apparatus using one sheet of the sensor substrate was described in Examples 1 to 6, plural sensor substrates may be packaged in adjoining relation with each other in order to form a more larger area of the X-ray image pick-up apparatus when the size of one sensor substrate is limited. An example of a large area X-ray image pick-up apparatus packaged by bonding plural substrates is described with reference to FIG. 14 and FIG. 15.

The sensor substrate **20** comprises a PIN type photodiode, TFT and a first SIN protective layer, on which a first polyimide flattening layer **15**, a scintillator layer **16** such as a CsI layer, a second polyimide flattening layer **18** and an Al reflection layer **17** are provided. A second SiN protective layer (not shown) may be further provided on the Al reflection layer **17**. The second SiN protective film may be provided for protecting the Al reflection film from being corroded during cutting off the sensor substrate.

The image pick-up device **200** having the construction as described above is cut-off with a diamond blade, and cut-off pieces were bonded on a substrate **21** with an adhesive **201** so as to dispose each piece in adjoining relation with each other as show in FIG. 14.

FIG. 15 shows a schematic cross section along the line A-A in FIG. 14. As shown in FIG. 15, a black resin **22** is filled into the gaps among the image pick-up devices in order to prevent optical crosstalk of the light whose wavelength has been converted with the scintillator. It is desirable to cover the end face of the sensor substrate with a resin **23** such as an epoxy resin when the end face is exposed. The gap between the image pick-up devices **200** is drawn larger than the actual size in FIG. 15 for the purpose of easy understanding of disposition of the resin **22**.

(Example 7)

Plural sensor substrates **20** are bonded followed by flattening in Example 7 according to the present invention.

A polyimide flattening layer **15** is coated after bonding plural substrates **20** on the substrate **21** as shown in FIG. 16A and FIG. 16B. The crossing portion after bonding, or the gap between the sensor substrates **20**, is once filled with the polyimide resin using a dispenser, followed by spin-coating the polyimide resin again over the entire surface of the substrate

to form a flattening layer **15**. Then, a scintillator layer **16** such as a CsI layer is deposited and an Al film **17** is formed after coating a second polyimide layer **18** on the scintillator layer **16**.

A black resin may be coated on the end face of the substrate and a part of the substrate (not shown) before bonding the substrate.

It is needless to say that the polyimide film **18** and Al film **17** may be formed on the end face of the scintillator, or the end face of the image pick-up device may be covered with a metal foil such as an aluminum foil.

Although the PIN type photodiode sensor is used as the photoelectric conversion element in the examples as hitherto described, a MIS type photosensor having the same construction as TFT may be used. An example of the X-ray image pick-up apparatus using the MIS type photosensor is disclosed in Japanese Patent Laid-open No. 7-250512.

FIG. 17A shows a schematic plane view of the portion corresponding to one pixel while FIG. 17B shows a schematic cross section of the portion indicated by a dot-in-broken line in FIG. 17A.

The reference mark **S11** denotes a photoelectric conversion element, the reference mark **T11** denotes a TFT, the reference mark **C11** denotes a capacitor and the reference numeral **SIG** denotes a signal line. The reference numeral **301** denotes a lower

electrode formed of Al or Cr provided on an insulation substrate such as a glass plate. The reference numeral **302** denotes an insulation layer made of, for example, silicon nitride (SiN) that prevents permeation of electrons and holes. The thickness of the insulation layer is adjusted to 500 Å or more that is a thickness enough for preventing permeation of electrons and holes by a tunnel effect. The reference numeral **303** denotes a photoelectric conversion semiconductor layer formed of an i-layer of an intrinsic semiconductor such as hydrogenated amorphous silicon (a-Si:H). The reference numeral **304** denotes an injection preventive layer formed of a n^+-layer of a-Si for preventing injection of holes from a transparent electrode **305** side to the photoelectric conversion semiconductor layer **303**. The transparent electrode **305** is made of a compound or an oxide containing indium or tin such as ITO. The reference numeral **306** denotes a SiN protective film.

It is clear from FIG. 17B that the photoelectric conversion element **S11** has the same construction as the TFT **T11**, and elements in the capacitor **C11** and photoelectric conversion element **S11** are not especially isolated or independent with each other but the capacitor **C11** is formed by expanding the electrode area of the photoelectric conversion element **S11**.

An example of packaging of the X-ray image pick-up apparatus and a X-ray image pick-up apparatus according to the present invention will be described below.

FIG. 18A and FIG. 18B denote a schematic construction and cross section of packaging of the X-ray image pick-up apparatus according to the present invention.

Plural photoelectric conversion elements and TFTs are formed on a sensor substrate **6011** forming a matrix. A shift resistor SRI and image pick-up integrated circuit IC are packaged on a flexible circuit board **6010** connected to the periphery of the sensor substrate **6011**. The back face of the flexible circuit board **6010** is connected to the circuit boards **PCB1** and **PCB2**. Plural sheets of the sensor susbtrate **6011** are bonded to a substrate **6012**, while a lead plate **6013** for protecting memories **6014** in a data processing circuit **6018** from X-ray is packaged under the substrate **6012** constituting the large area photoelectric converter. A scintillator **6030** such as CsI as a wavelength converter for converting X-ray into visible light is deposited on the sensor susbtrate **6011** after flattening the substrate. The overall system is housed in a case **6020** made of a carbon fiber as shown in FIG. 18B.

FIG. 19 illustrates an example of the X-ray image pick-up apparatus applied to a X-ray diagnosis system.

X-ray emitted from a X-ray tube **6050** transmits the chest **6062** of a patient or examination subject **6061** and impinges a photoelectric converter **604** on which the scintillator is packaged. The incident X-ray involves information in the body of the patient **6061**. The scintillator emits a light in response

to the incident X-ray, the light being converted into electric signals to obtain electric information. The information is converted to digital signals that are subjected to image processing to obtain an image observable on a display **6080** in the control room.

This information can be also transferred to a remote site with a transmission mean such as a telecommunication network, or can be watched on a display **6081** installed at a separated doctor room to enable a doctor residing at a remote site to make a diagnosis. The information can be of course either stored on storage **6082** and **6083** such as an optical disk, or recorded on a film **6110** with a film processor **6100**.

As hitherto described, crystallinity of CsI constituting the scintillator layer as a wavelength converter can be improved according to the present invention. Moreover, a highly reliable reflection film and protective film can be manufactured by flattening the surface roughness of the CsI scintillator layer.

When the apparatus is manufactured by bonding plural sensor substrates, it is possible to uniformly form the CsI scintillator layer on the plural substrates.

Consequently, substantial aperture ration can be enhanced to provide a highly sensitive and high-speed image pick-up apparatus.

The wavelength converter according to the present invention has excellent characteristics owing to improved and

uniform crystallinity of CsI with good repeatability, thereby making it possible to prevent sensitivity from being distributed to enable an excellent image information to be obtained.

A high reliable image pick-up apparatus with good durability can be manufactured with good yield according to the present invention, making it possible to manufacture the apparatus with low production cost.